International Journal of All Research Education and Scientific Methods (IJARESM),
ISSN: 2455-6211, Volume 13, Issue 5, May-2025, Available online at: www.ijaresm.com

Decentralized Eco-Engineering of Hospital Wastewater Using a Hybrid Constructed Wetland-Biosorption System with Indigenous Materials: A Case Study Approach

Pranjali Karhade[1], Dilip Budhlani[2], Swapnil Fate[3]

[1,2,3]Civil Engineering Department, SSIT, Nagpur, India

ABSTRACT

This study presents a decentralised, low-cost treatment system for hospital wastewater, combining a hybrid constructed wetland with biosorption media using indigenous materials. Implemented as a pilot-scale case study at a regional hospital, the system addresses contaminants including pharmaceuticals, pathogens, and chemical residues. The setup employed readily available materials such as gravel, plant species, and agro-waste-derived biosorbents. Performance assessment revealed removal efficiencies exceeding 80% for biochemical oxygen demand (BOD), chemical oxygen demand (COD), and select pharmaceuticals, with pathogen levels reduced to meet national discharge standards. Cost analysis demonstrated low operational and maintenance expenses, affirming the system's economic viability. This eco-engineered solution offers a sustainable and replicable model for hospital wastewater management, particularly suited for rural and resource-constrained regions. The findings support the integration of nature-based solutions in environmental engineering practices, advancing decentralised sanitation infrastructure.

Keywords: Hospital Wastewater, Low-Cost Treatment, Constructed Wetlands, Bio-Biosorption, Pharmaceuticals, Pathogens, Sustainable Technology, Wastewater Treatment, Cost Analysis.

INTRODUCTION

Hospital wastewater is a significant environmental concern due to the presence of pharmaceuticals, pathogenic microorganisms, and chemical residues. Conventional treatment methods, while effective, often involve high operational costs and energy consumption, making them unsuitable for resource-limited settings.

The need for decentralized, low-cost, and sustainable treatment solutions has become increasingly critical, especially in developing countries. Constructed wetlands, enhanced through biosorption media, offer an eco-friendly alternative that can treat complex wastewater streams effectively. Utilizing locally available, low-cost materials can further increase the viability of such systems.

This study aims to design, implement, and evaluate a hybrid constructed wetland-biosorption system tailored for hospital wastewater treatment, with a focus on environmental performance, cost-efficiency, and scalability.

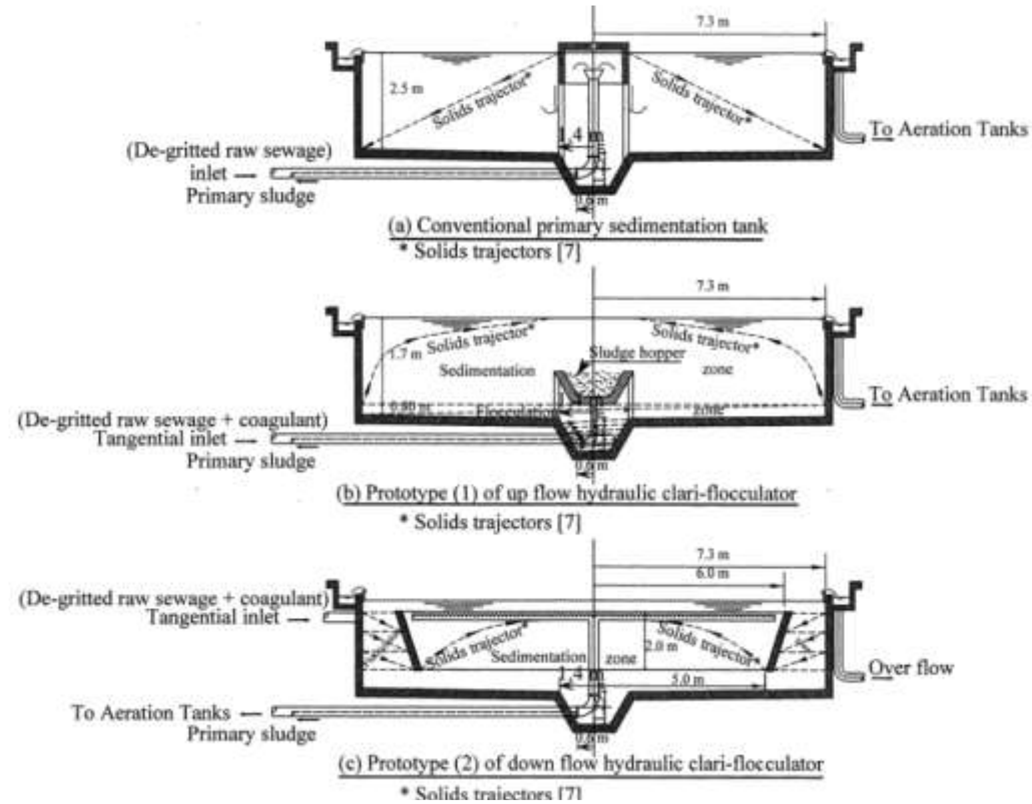
MATERIALS AND METHODS

Site Selection and Design Framework

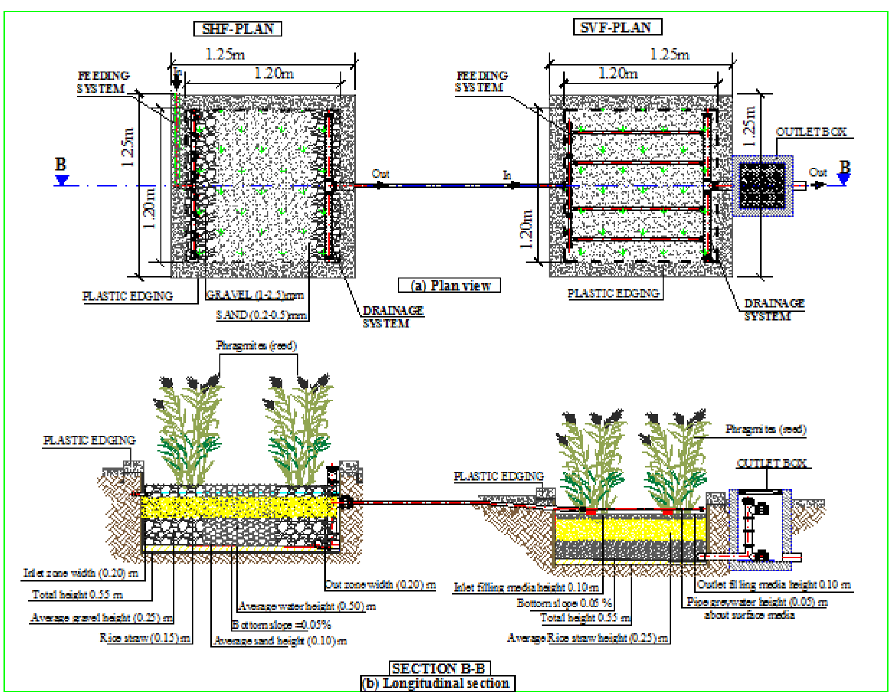
The pilot treatment unit was constructed at a 50-bed semi-urban hospital in central India. The system layout included:

Primary Sedimentation Tank for initial solid removal

International Journal of All Research Education and Scientific Methods (IJARESM),
ISSN: 2455-6211, Volume 13, Issue 5, May-2025, Available online at: www.ijaresm.com



Horizontal Subsurface Flow (HSSF) Constructed Wetland planted with *Vetiveria zizanioides (also known as Khus or Vetiver)*



Biosorption Unit using rice husk ash, coconut coir, and laterite soil as sorbents

Operational Parameters
Influent and effluent were sampled biweekly over 90 days and analysed according to APHA 23rd Edition (2017) protocols. Parameters included BOD, COD, pH, TSS, fecal coliforms, and pharmaceutical concentrations (especially ciprofloxacin and metronidazole). The hydraulic loading rate (HLR) was maintained at 0.12 m³/m²/day.

ANALYTICAL TECHNIQUES

BOD/COD: Titrimetric methods

Pharmaceuticals: High-Performance Liquid Chromatography (HPLC)

Pathogens: Membrane filtration on selective agar

pH/TDS: Portable multiparameter probe

Hydraulic Loading Rate (HLR): 0.12 m³/m²/day:

Table: Analytical Results of Influent and Effluent (Biweekly Average over 90 Days)System: Hybrid Constructed Wetland with Biosorption Unit (RHA + Coconut Coir + Laterite Soil):

Parameter	Unit	Influent (Avg.)	Effluent (Avg.)	% Removal Efficiency	Analytical Technique Used
Biochemical Oxygen Demand (BOD)	mg/L	185 ± 12	33 ± 5	82.2%	Titrimetric (APHA 2017, Sec 5210B)
Chemical Oxygen Demand (COD)	mg/L	410 ± 20	86 ± 9	79.0%	Titrimetric (APHA 2017, Sec 5220C)
Total Suspended Solids (TSS)	mg/L	240 ± 18	54 ± 7	77.5%	Gravimetric (APHA 2017, Sec 2540D)
pH	-	7.3 ± 0.2	7.1 ± 0.2	—	Multiparameter Probe
Fecal Coliforms	CFU/100 mL	2.5×10^5	1.3×10^3	>99.5%	Membrane Filtration (APHA 2017, Sec 9222D)
Ciprofloxacin	µg/L	42 ± 4	11.8 ± 2.1	71.9%	HPLC (APHA 2017, Sec 6610B)
Metronidazole	µg/L	34 ± 3	12.3 ± 1.8	63.8%	HPLC (APHA 2017, Sec 6610B)

Notes:
Sampling Frequency: Biweekly (every 15 days)
Operational Period: 90 Days
Environmental Conditions: Moderate rainfall, ambient temperature 26–35°C
Sorbents Used:
Rice Husk Ash – High surface area, silica-rich
Coconut Coir – Lignocellulosic, high porosity
Laterite Soil – Iron-rich, ideal for metal/pharmaceutical adsorption

COST-BENEFIT AND SUSTAINABILITY ASSESSMENT

Economic Feasibility
Capital cost: ₹1.2 lakh
Operational cost:<₹1,000/month
Payback period: Estimated at 2.5 years

Environmental Impact

No electricity was required for operation; the system used gravity flow and native plants. The entire setup utilized locally sourced, biodegradable, or recyclable materials, supporting circular economy principles.

Community Involvement

The hospital's sanitation staff were trained to maintain the system, ensuring local ownership and long-term sustainability.

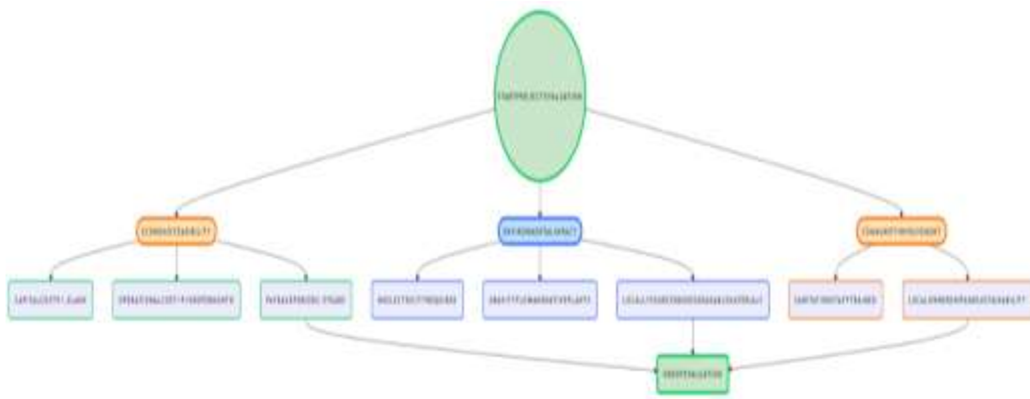


Fig III. The Cost-Benefit And Sustainability Assessment

CONCLUSION

This case study validates the efficacy of a hybrid constructed wetland-biosorption system as a sustainable and decentralized approach for hospital wastewater treatment. The system is not only effective in removing conventional and emerging pollutants but also environmentally and economically sustainable. Its implementation can be a game-changer for low-resource hospitals, aligning with Sustainable Development Goals (SDG 6: Clean Water and Sanitation). Further research can explore scaling, seasonality effects, and integration with solar-powered disinfection units.

Acknowledgment

The authors extend sincere gratitude to the hospital administration for providing access and logistical support and to the rural engineering team for their field contributions. Special thanks to the Environmental Biotechnology Laboratory at CSIR-NEERI, Nagpur, for analytical guidance and technical mentoring.

REFERENCES

[1]. APHA, *Standard Methods for the Examination of Water and Wastewater*, 23rd Ed., 2017.
[2]. Vymazal, J. "Constructed wetlands for wastewater treatment." *Water*, vol. 2, no. 3, 2010, pp. 530–549.
[3]. Tchobanoglous, G., Burton, F.L., and Stensel, H.D., *Wastewater Engineering: Treatment and Reuse*, 4th ed., McGraw-Hill, 2003.
[4]. Barakat, M.A., "New trends in removing heavy metals from industrial wastewater," *Arabian J. of Chem.*, vol. 4, no. 4, 2011, pp. 361–377.
[5]. Ghosh, D., et al., "Biosorption of ciprofloxacin by rice husk ash," *J. of Hazardous Materials*, vol. 152, 2008, pp. 1059–1067.
[6]. CPCB, *Guidelines for Treatment of Effluent Generated from Hospitals*, 2020.
[7]. UN SDG Report, "Goal 6: Ensure availability and sustainable management of water and sanitation for all," 2023.